Listening for thunder beyond the clouds

Using the grid to analyse gravitational wave data

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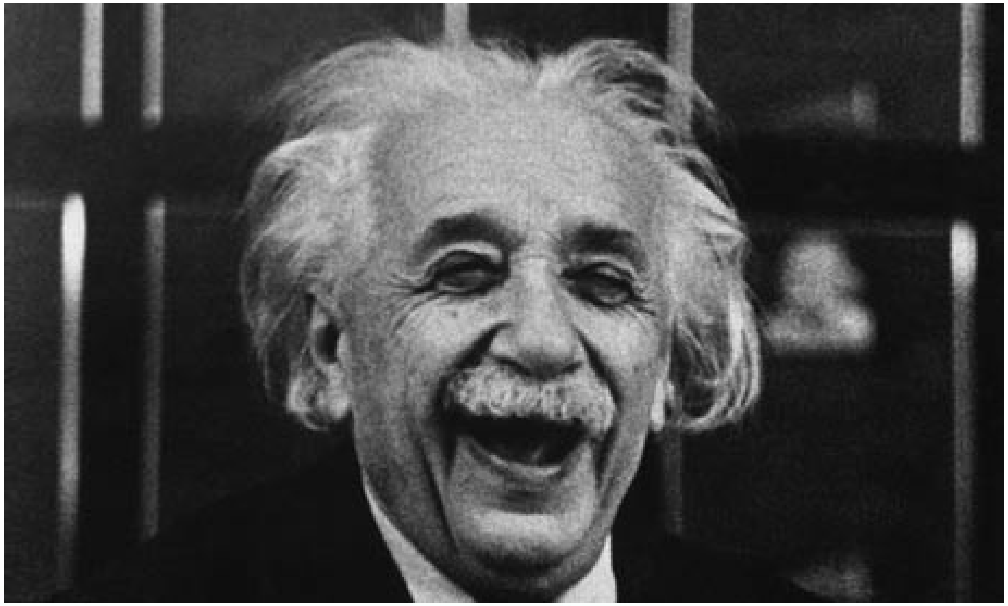
Overview

1. Gravitational wave (GW) observatories
2. Analysis of continuous GWs
3. GWs and multi-messenger astronomy
4. Hardware acceleration: the 'Chimera'
5. Future directions

1: Gravitational waves

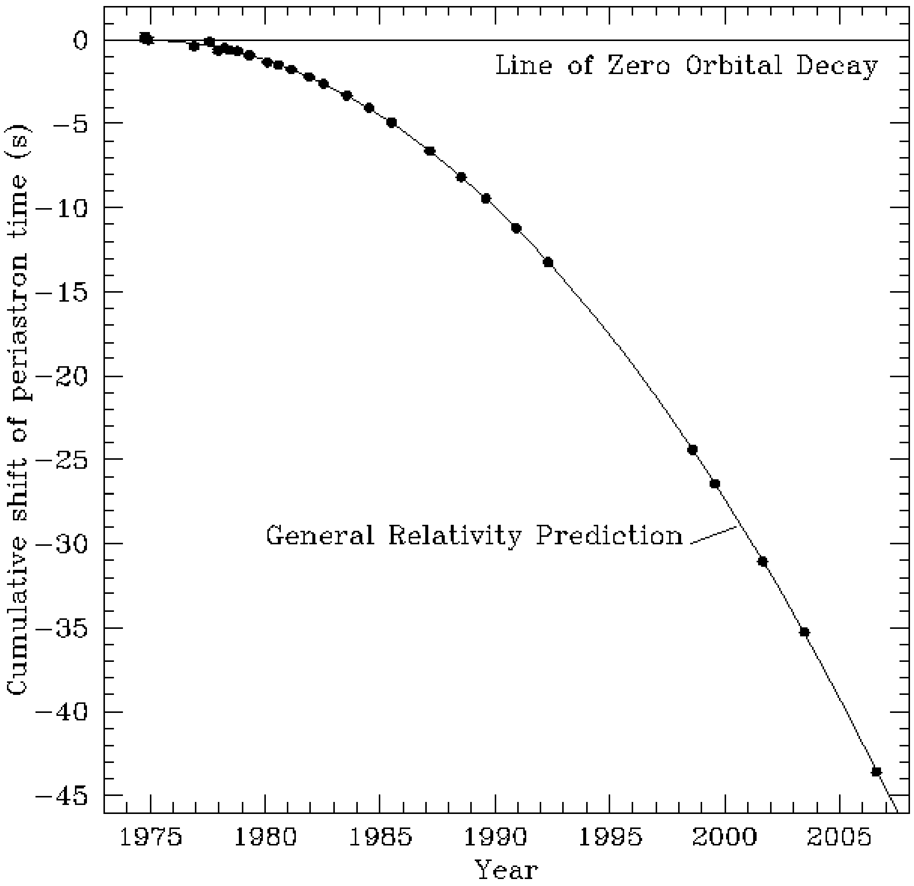
- Consequence of Einstein's Theory of General Relativity*
- Effectively detected as mechanical waves (but *of*, not *through* space-time!)



*Although not without controversy! Enter “Who's afraid of the referee?” into your search engine

Hulse and Taylor: 1993 Nobel Prize in Physics

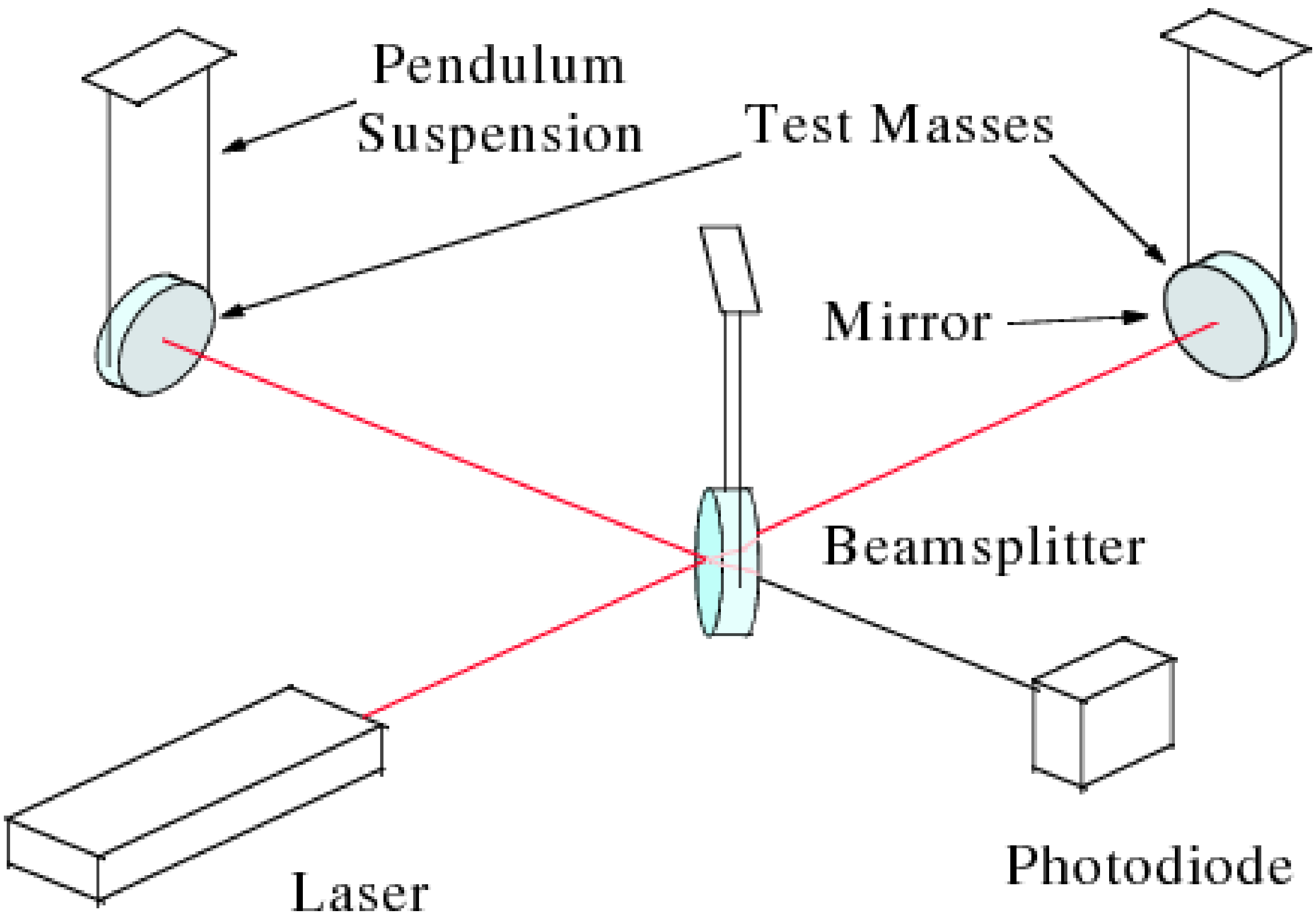
- Perfect agreement with prediction from GR
- No direct detections (yet!)



LASER interferometers

Michelson laser interferometer: sensitive, broad-band

Non-directional: need a network to get position observations



LIGO: Laser Interferometer Gravitational-wave Observatory

- 4km baseline Michelson interferometer
- Equivalent precision to measuring the distance to Uranus using a scanning electron microscope

The LIGO-Virgo Network

The LIGO Data Grid

DOE issued grid (X.509) certificates

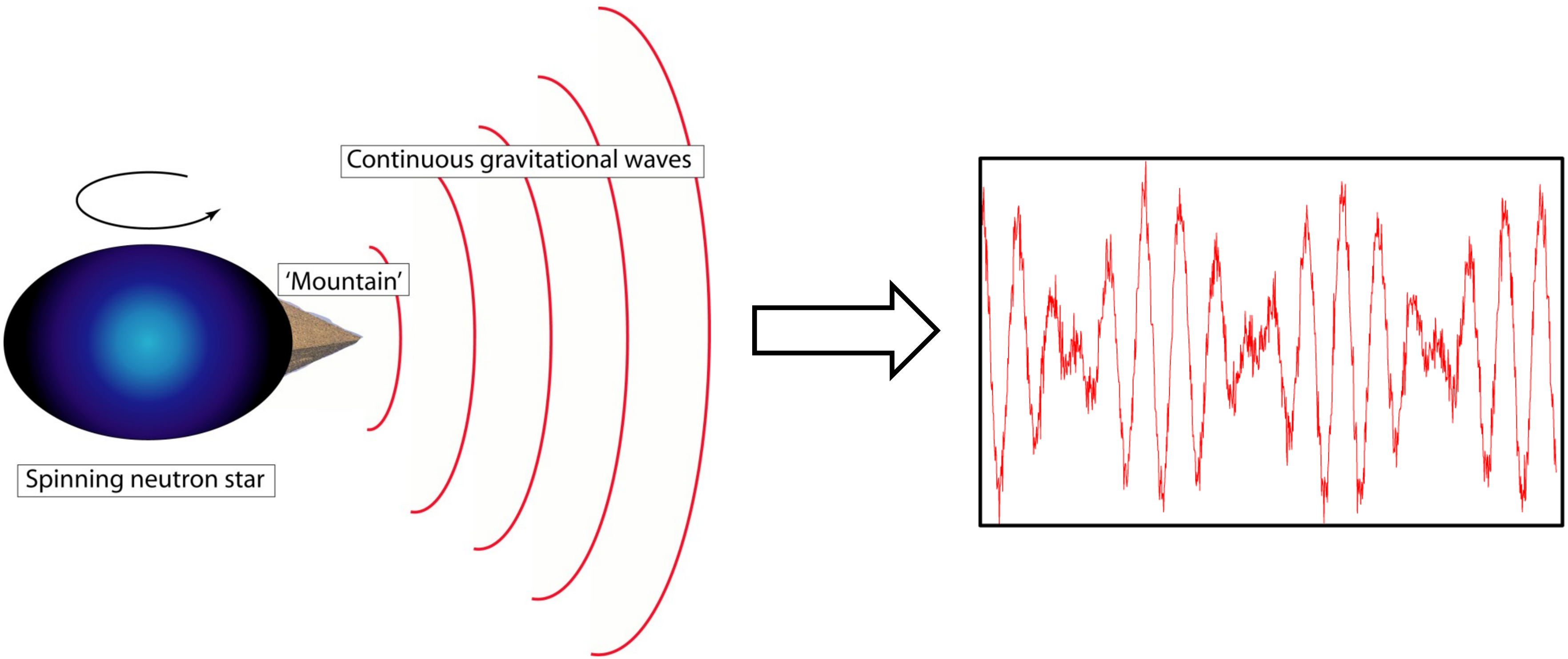
Australian Certificate Authority administered by Australian Research Collaboration Service (ARCS)

Globus-based grid distribution, with five main cluster centres

Preferred job handling system: Condor

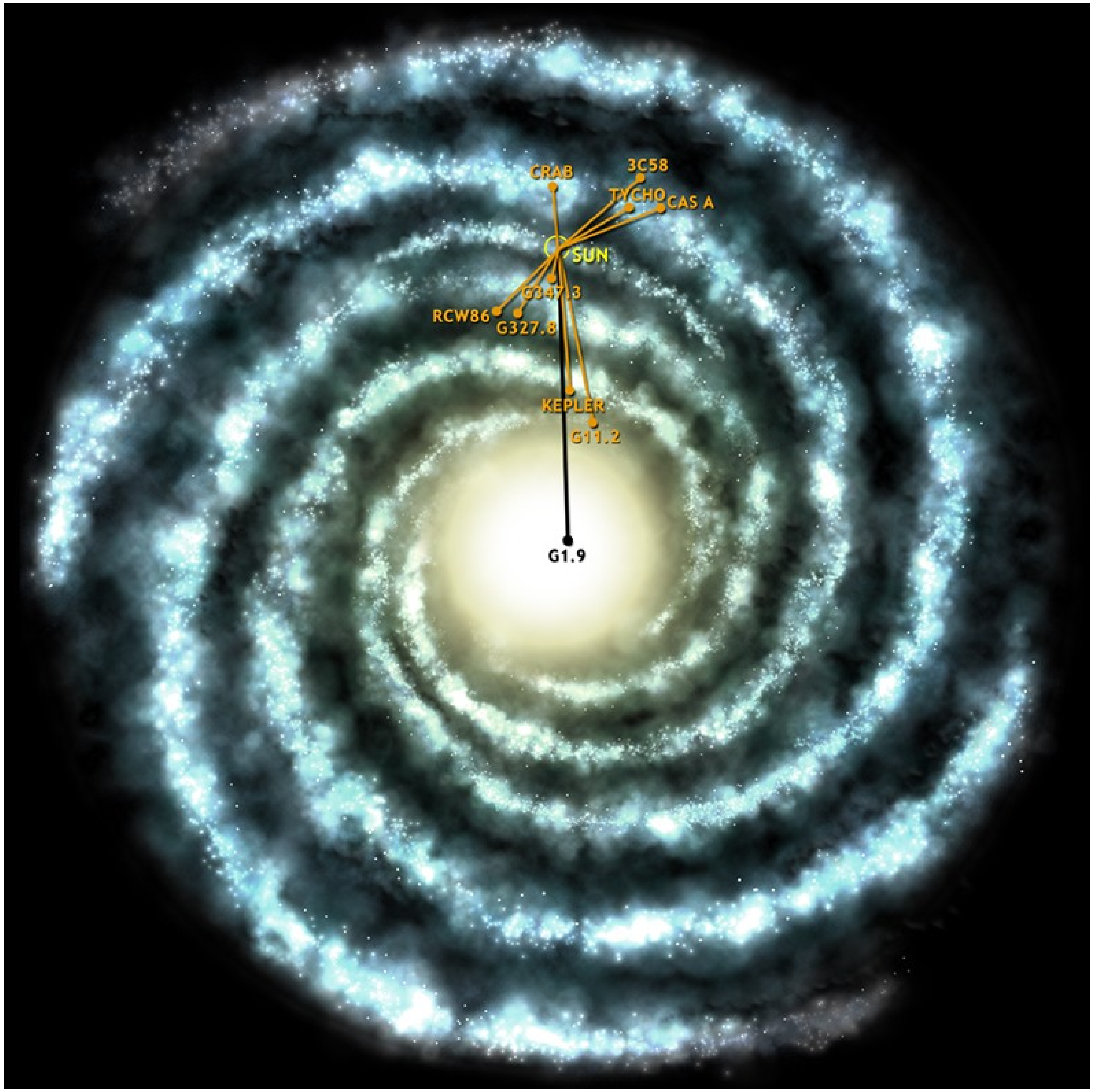
(http://research.cs.wisc.edu/condor/)

2: Continuous GWs



- Rotating, non-axisymmetric neutron stars
- Signal model relatively well understood
- Low h_0, so average over long time

- Supernova remnants
- Young
- Isolated
- Unknown f0



Karl Wette's Cas A paper:
J. Abadie *et al.*: "First search for gravitational waves from the youngest known neutron star", *Astrophysical Journal* **722**(2), pp.1504–1513 (2010)

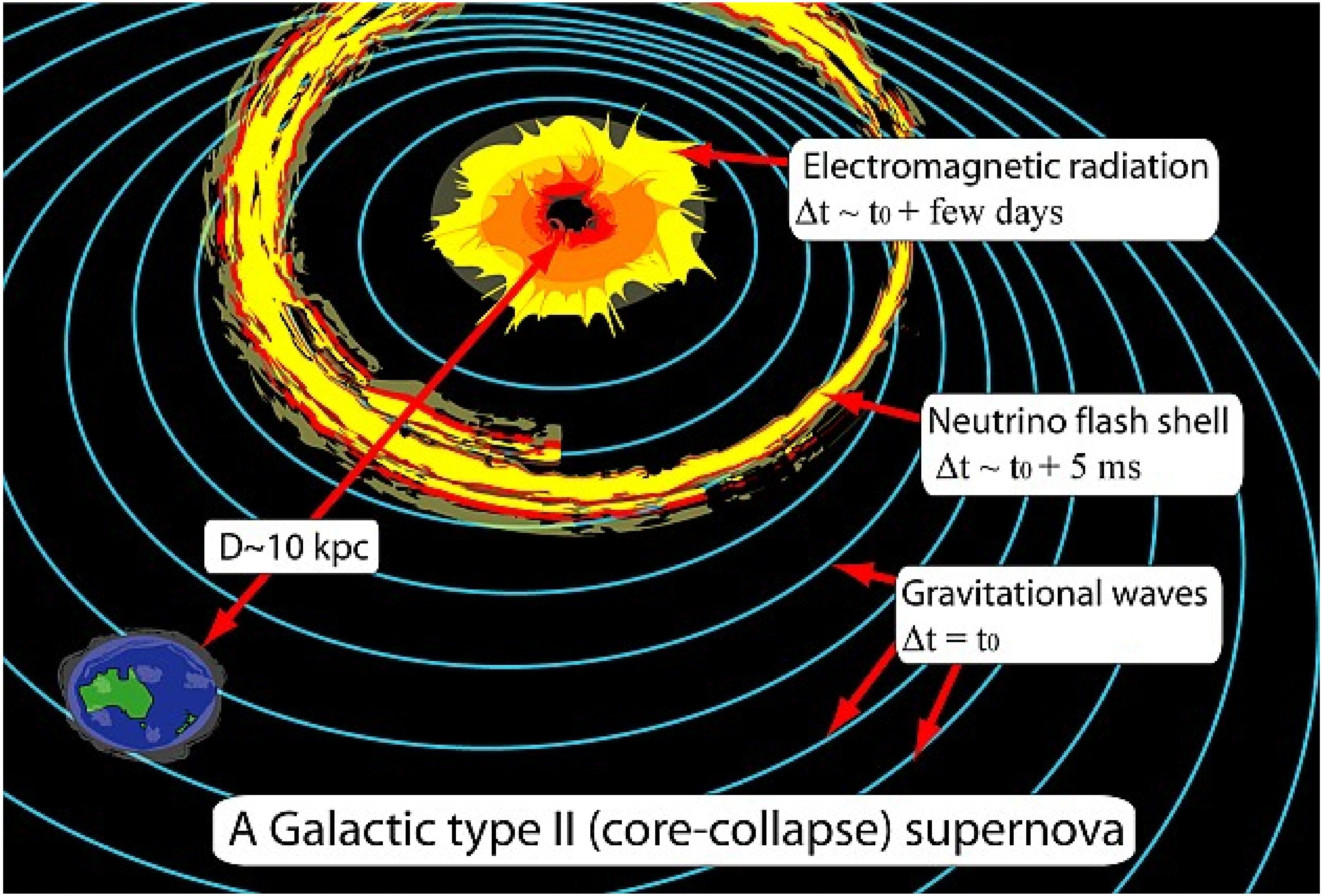
Computational cost

- Massive amount of averaging required
- Have to judiciously lay template banks
- Each target: > 400,000 CPU hours on AEI's Atlas (120 Tflop/s)
- Searches ongoing...

3: GWs and multi-messenger Astronomy

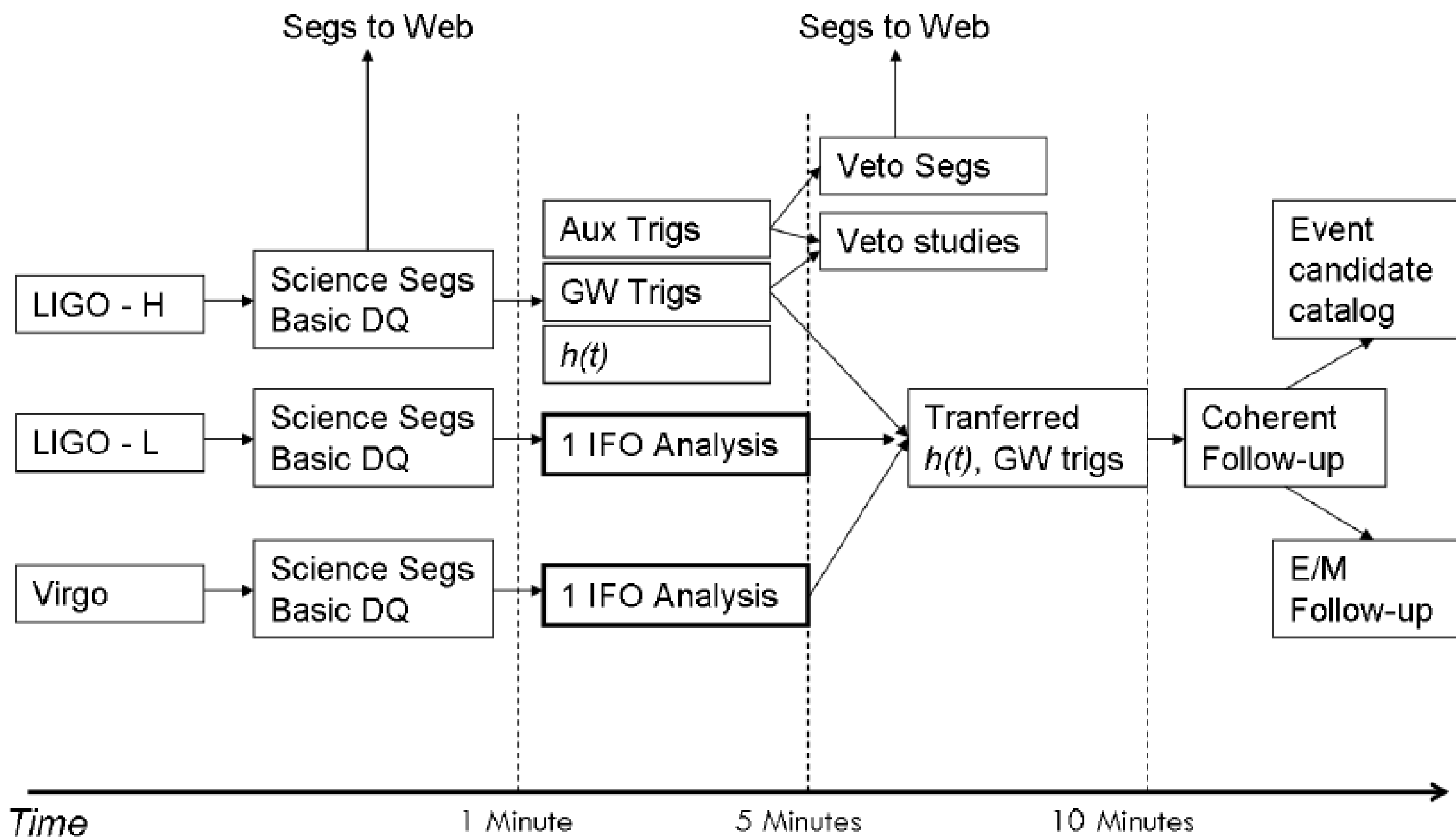
- Robotic telescopes + cheap, better CCDs = Transient Astronomy
- Transients highly energetic, creating a menagerie of carrier waves ('messengers')
- Most interesting transients very short lived (~few milliseconds to hours)

GWs: the vanguard messengers



GW Network to Optical Network

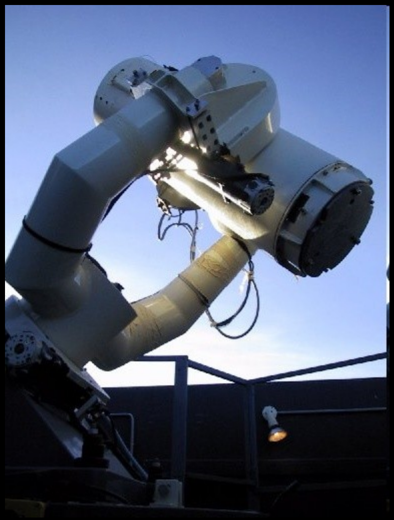
Low latency trigger pipeline



QUEST camera on
ESO Schmidt Telescope

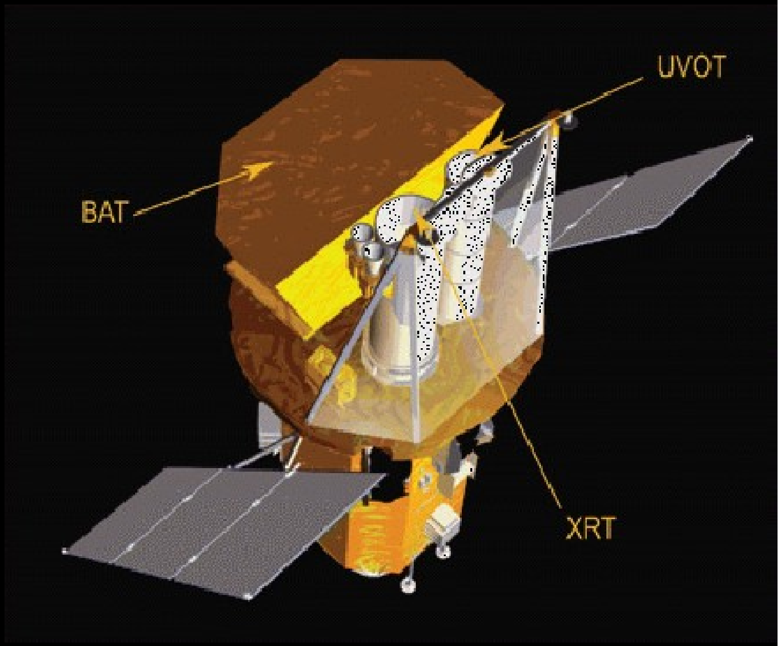
- 4.1 x 4.6 deg FOV
- Survey telescope for supernovas, etc.

TAROT
Chile & France



- 1.85 x 1.85 deg. FOV
- History of GRB follow-ups

Swift Satellite



- UV/optical telescope: 0.4x0.4 sq. deg. FOV
- X-ray telescope: 0.3x0.3 sq. deg. FOV

Slide courtesy of Jonah Kanner and the LIGO-Virgo collaboration

ANU: SkyMapper (Australia)

SkyMapper

2.4 x 2.4 deg. FOV

Robotic survey telescope

Commissioned and led
by Brian Schmidt

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Results

- Successfully processed a handful of transient candidates
- Worst total latency: 30 mins
- Couldn't do low latency without grid middleware
- Secure socket to telescopes
- High level of automation, but still required 'human in the loop'
- Had to use wget...

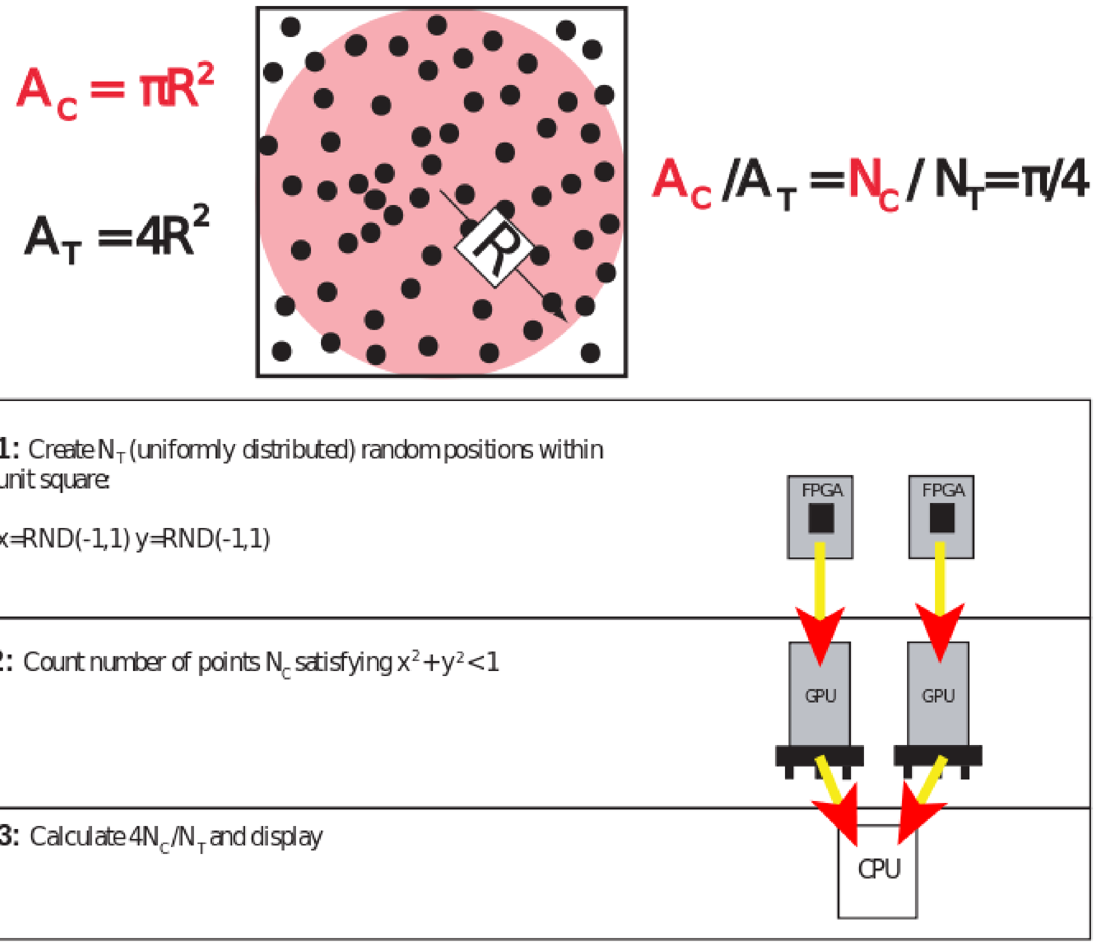
4: Hardware acceleration

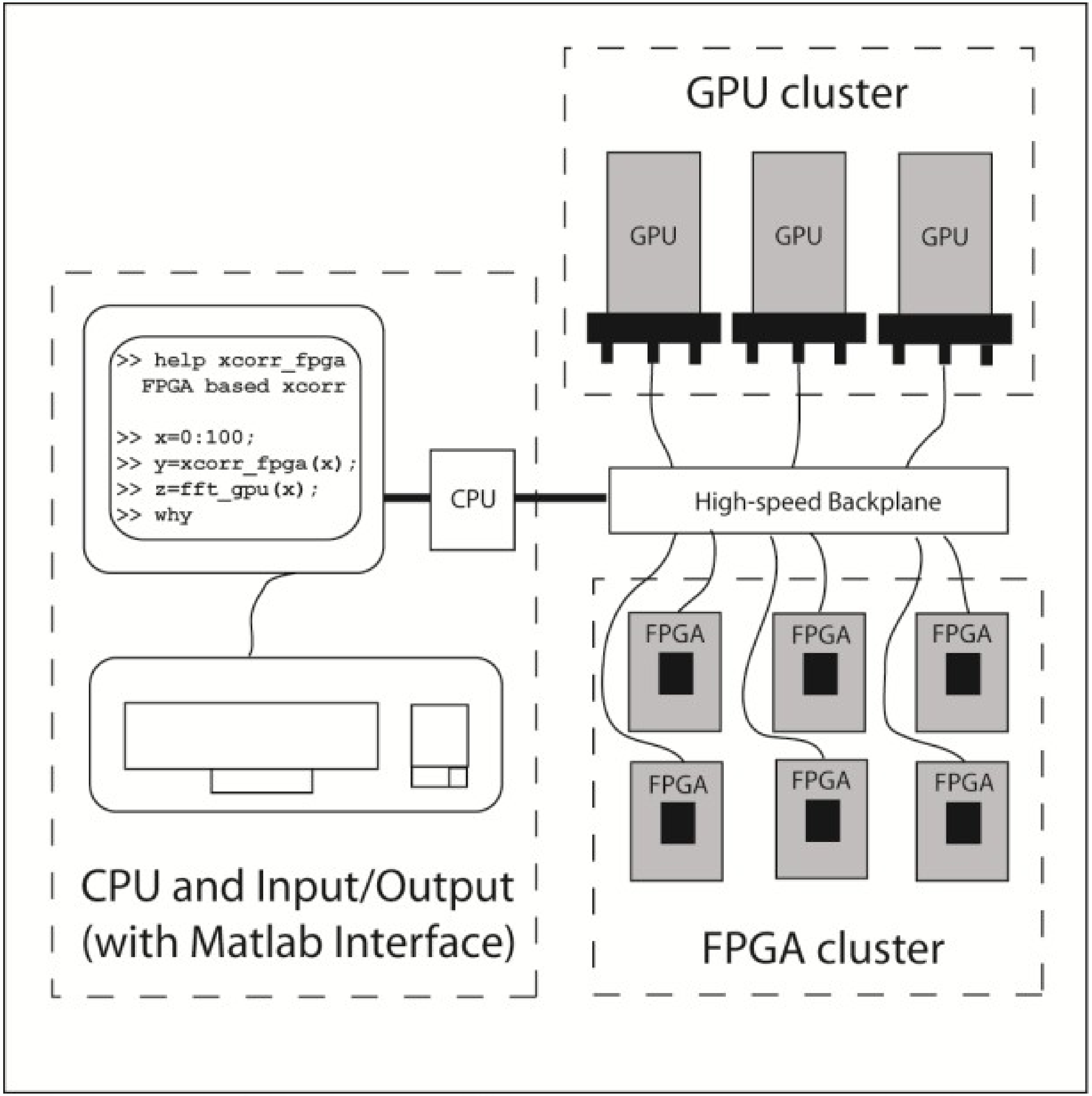
- Desktop HPC solution
- Highly heterogeneous: makes use of both GPGPU* and FPGA** hardware acceleration

Platform	Pros	Cons
CPU	Analysis 'workhorse', multi-tasking	Power hungry, limited cores
GPGPU	Highly parallel, fairly simple interface (e.g. C for CUDA)	Highly rigid instruction set (can't handle complex pipelines)
FPGA	Unrivalled flexibility and pipelining	Expensive outlay, specialised interface

*(General Purpose) Graphical Processor Unit **Field Programmable Gate Array

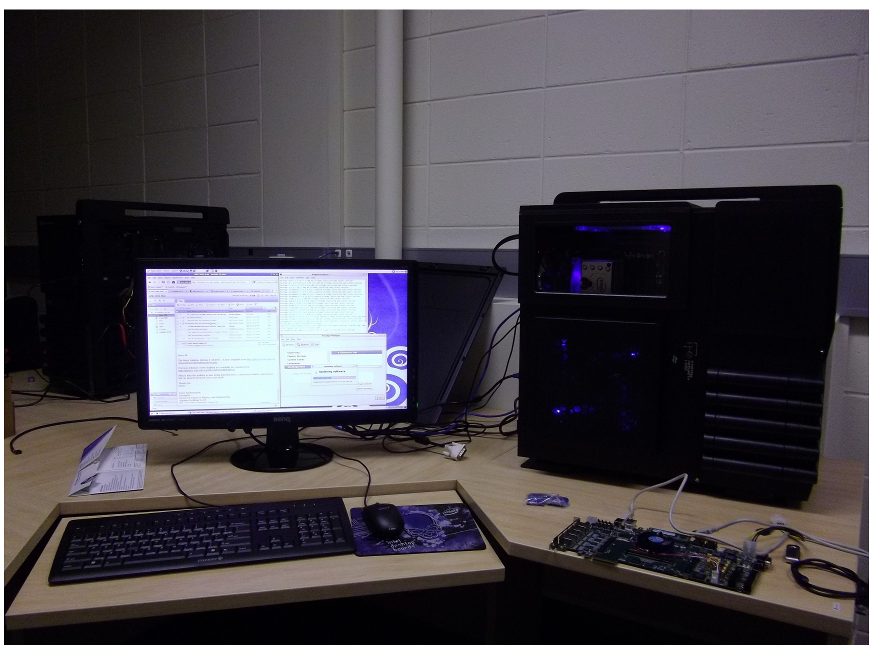
Monte Carlo calculation of π

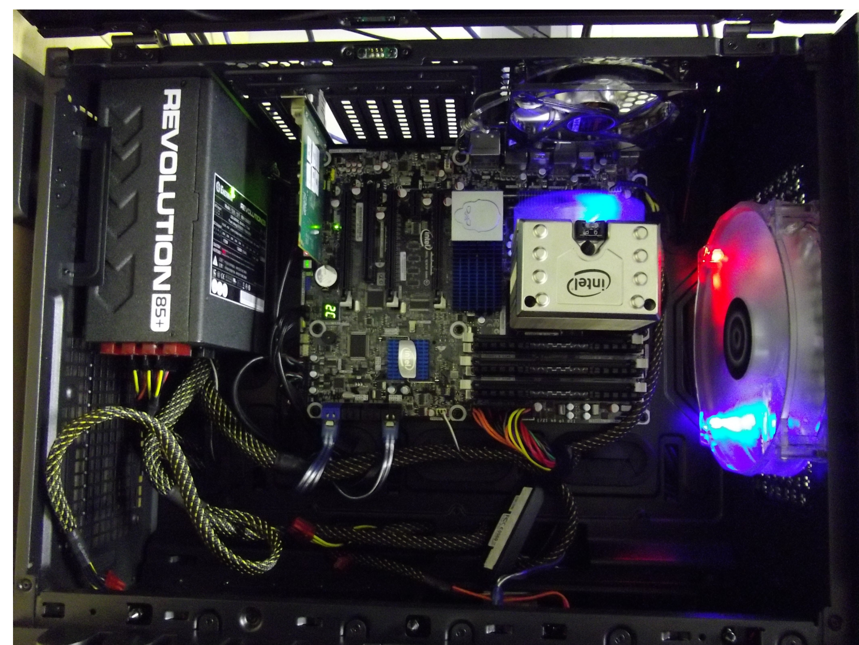



GPU cluster
GPU
GPU
GPU
>> help xcorr_fpga
FPGA based xcorr
>> x=0:100;
>> y=xcorr_fpga(x);
>> z=fft_gpu(x);
>> why
CPU
High-speed Backplane
FPGA
FPGA
FPGA
FPGA
FPGA
FPGA
CPU and Input/Output
(with Matlab Interface)
FPGA cluster

The 'Chimera'

Subsystem	Vendor	Model
CPU	Intel	i7 Hexacore
(GP)GPU	nVidia	Tesla C2075
FPGA	Altera	Stratix-IV





Bottleneck

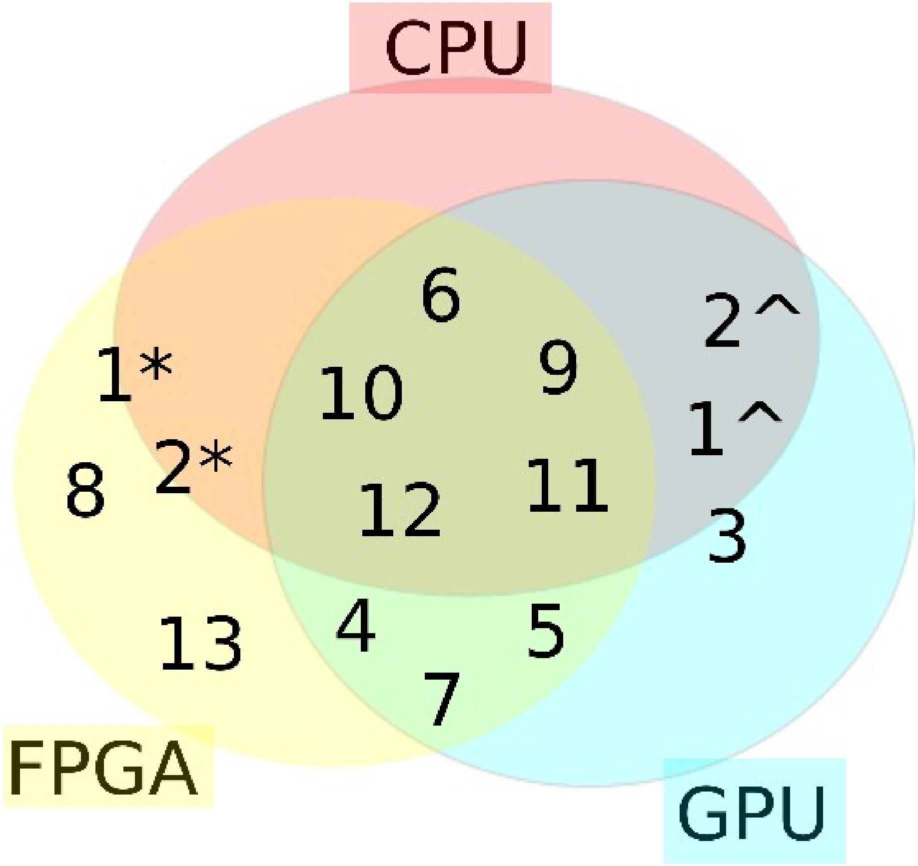
- 'High-speed backplane' = PCIe bus (!)
- Currently working on PCIe kernel modules

The Chimera vs the Dwarves

- Phil Colella: 7 separate classes ('Dwarves') of parallel algorithm
- UC Berkeley study: extended to 13

K. Asanovic and U. C. Berkeley Computer Science Dept.: “The Landscape of Parallel Computing Research: A View from Berkeley,” Tech. Rep. UCB/EECS-2006-183 (UC Berkeley, 2006).

	Dwarf	Subsystem
1	Dense matrix	FPGA*, GPU^
2	Sparse matrix	FPGA*, GPU^
3	Spectral	GPU
4	N-body	FPGA+GPU
5	Structured grid	FPGA+GPU
6	Unstructured ''	FPGA+GPU+CPU
7	MapReduce	FPGA+GPU
8	Combinatorial	FPGA
9	Graph traversal	FPGA+GPU+CPU
10	Dynamic prog.	FPGA+GPU+CPU
11	Backtrack/B&B	FPGA+GPU+CPU
12	Graphical mods	FPGA+GPU+CPU
13	Finite State	FPGA



5: Future directions

- Fully automate image analysis pipeline (lower latency)
- Finalise CW searches
- Higher speed backplane for Chimera

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Thanks for listening!

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Image: http://wallpaper-million.com/download/Lightning-storm-in-space-wallpaper_2976.html